6 Statistical Quality Control for Aggregate Processing

Process Characteristics

Continuous Processing
Product Alteration
Multiple Products

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Precision
Capability

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CHAPTER SIX: STATISTICAL QUALITY CONTROL FOR AGGREGATE PROCESSING

The process of producing and shipping mineral aggregate is a relatively simple one. It does not require high technology, and the methods chosen to control that process should be equally as simple. Those methods, however, account for all the many difficulties a producer may encounter. Each time a decision is made that affects the process at least three principle characteristics of this industry should be kept in mind: continuous processing, product alteration, and multiple products.

PROCESS CHARACTERISTICS

CONTINUOUS PROCESSING

Generally, a continuous run of material is produced which tends to lose its identity through stockpiling and shipping. Good controls as far upstream as possible in production are very important.

PRODUCT ALTERATION

All aggregate products degrade and segregate with handling and time. This phenomena occurs from beginning to the end of any process. It must also be understood that this occurs later, such as when the products are under the customer's control.

MULTIPLE PRODUCTS

Most operations make more than one product concurrently. A change in one product can affect each and every one of the other products.

QUALITY CONTROL

Generally speaking, the process control techniques that are most desirable are **predictive** in nature rather than **detective** techniques that provide information on the product after it has been stockpiled for shipping. Quality Control is the prediction of product performance within pre-established limits for a desired portion of the output. Two principles of Quality Control that should be adhered to are:

1. Make sure the correct target is understood and achievable.

2. Control variability within pre-established limits.

Once the techniques for prediction of performance are developed, then Quality Control must address three issues: accuracy, precision, and capability.

ACCURACY

If the average of all measurements falls relatively close to an understood point (on target), then the process is said to be **accurate**.

PRECISION

When all of the measurements over time are very close together, then the process is said to be **precise**.

CAPABILITY

If the process is both accurate and precise such that it remains within specification or other predetermined limits with a high degree of confidence, then it is said to be **capable**.

Figure 6-1 gives a graphical representation of accuracy, precision, and capability.

Accuracy, Precision, and Capability

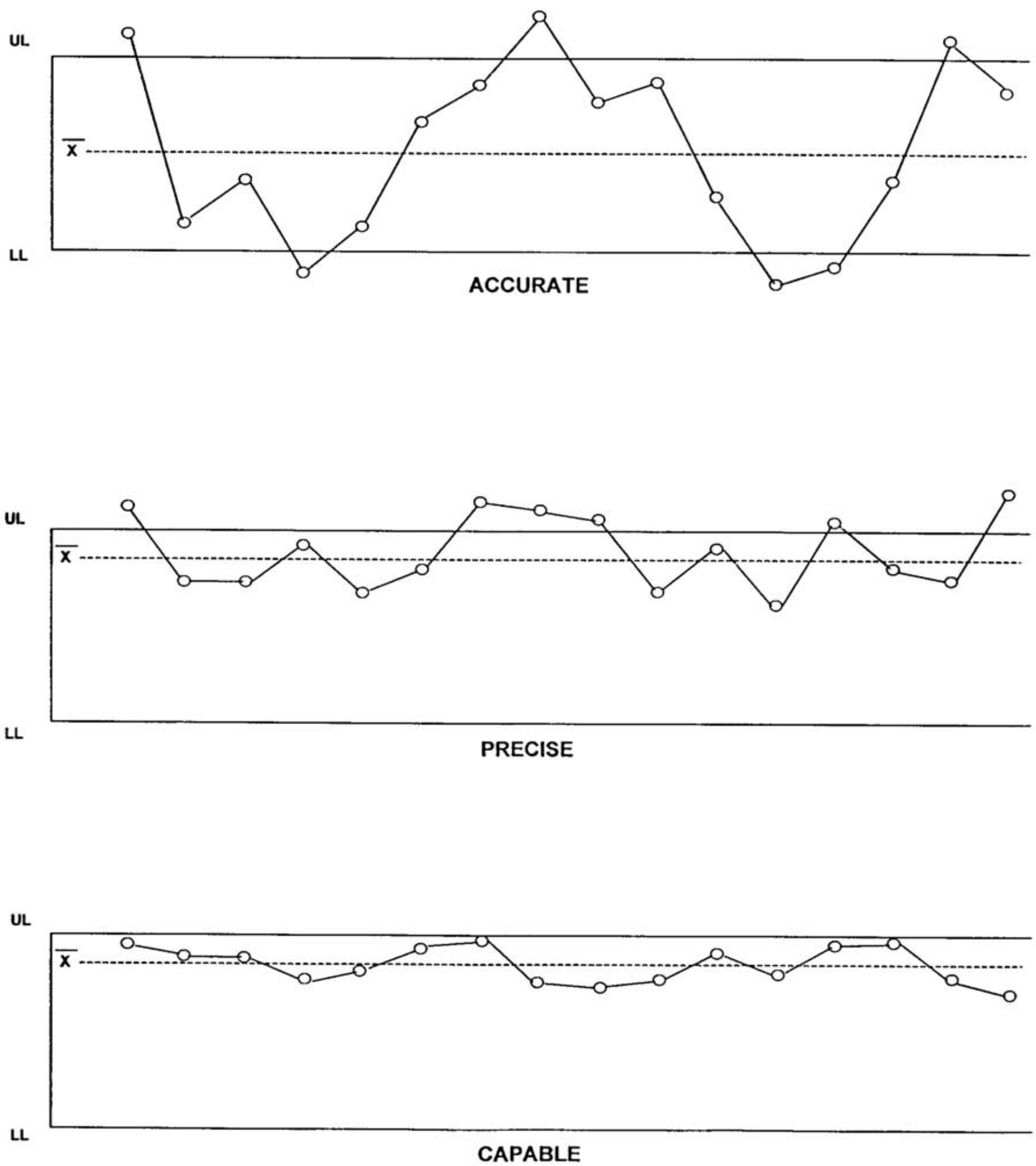


Figure 6-1

UNDERSTANDING THE PROCESS

Trying to control an unstable process is like trying to answer an unsolvable riddle. Nothing is predictable; hence, nothing can be assumed. You must follow a logical path to understand how, when, and what controls are necessary. The following path is a series of measurements, observations, communications, and decision-making.

CURRENT PROCESS

The current process must be thoroughly understood before making wise decisions on how to make improvements:

1) Gather honest employee input so that management knows what they know;

2) Conduct and document visual observations of which elements seem to cause the greatest variability. Excavating or blasting, crushing, screening, total process stockpiling, and hauling, handling, and loading are all items that may affect quality; and

3) Learn how and make accurate measurements at uniform intervals over time. Apply statistical principles to determine current stability and capability of the process.

PROCESS STABILITY

The process must first be stabilized before any other improvements can be made:

1) Identify the variables that most affect the process, called the Key Process Variables. These should receive the greatest attention from operations managers (Figure 6-2);

2) Establish standards. The first reduction in variability can be recognized through "Standard Operating Procedures" (S.O.P.'s) namely, job descriptions, measurements (type and frequency), protocol for extreme conditions, etc; and

3) Determine **special causes**. An absolute requirement for a stable process is the elimination of special causes of variability, namely, the ones that are external and not a part of the natural process. (e.g. conditions created by personnel)

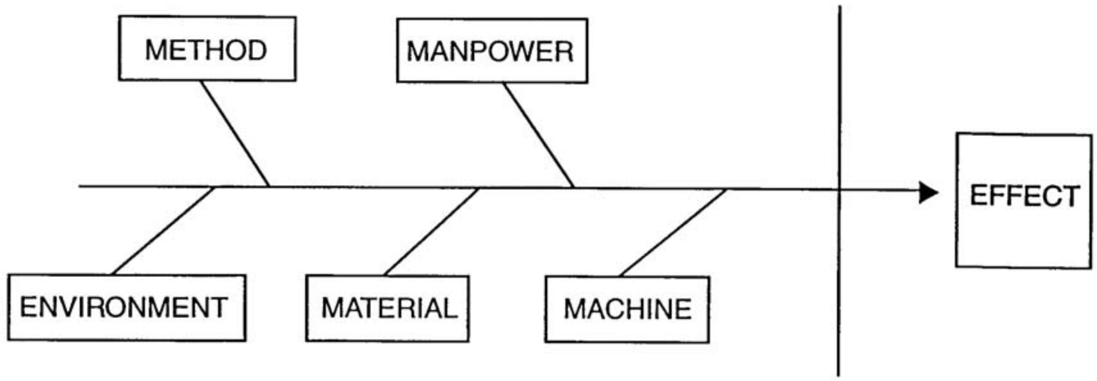


Figure 6-2. Key process variables.

DECISION-MAKING

After operating for some time with a stable process, some important decisions can be made. There are two things that must occur first:

1) Communicate with customers so they understand the new stable products. Also, get input from them on the need for further adjustment; and

2) Make concurrent measurements to assess the need for further improvement.

PROCESS CAPABILITY

Decisions previously made should include any techniques needed to bring the process into desired compliance with a high degree of confidence.

1) Establish final desired product targets and limits; and

2) Reduce common causes of variability as required. This generally means a change in the process.

PROCESS CONTROL

Implement ongoing statistical process control along with continuous improvement.

STEPS FOR MANAGING QUALITY

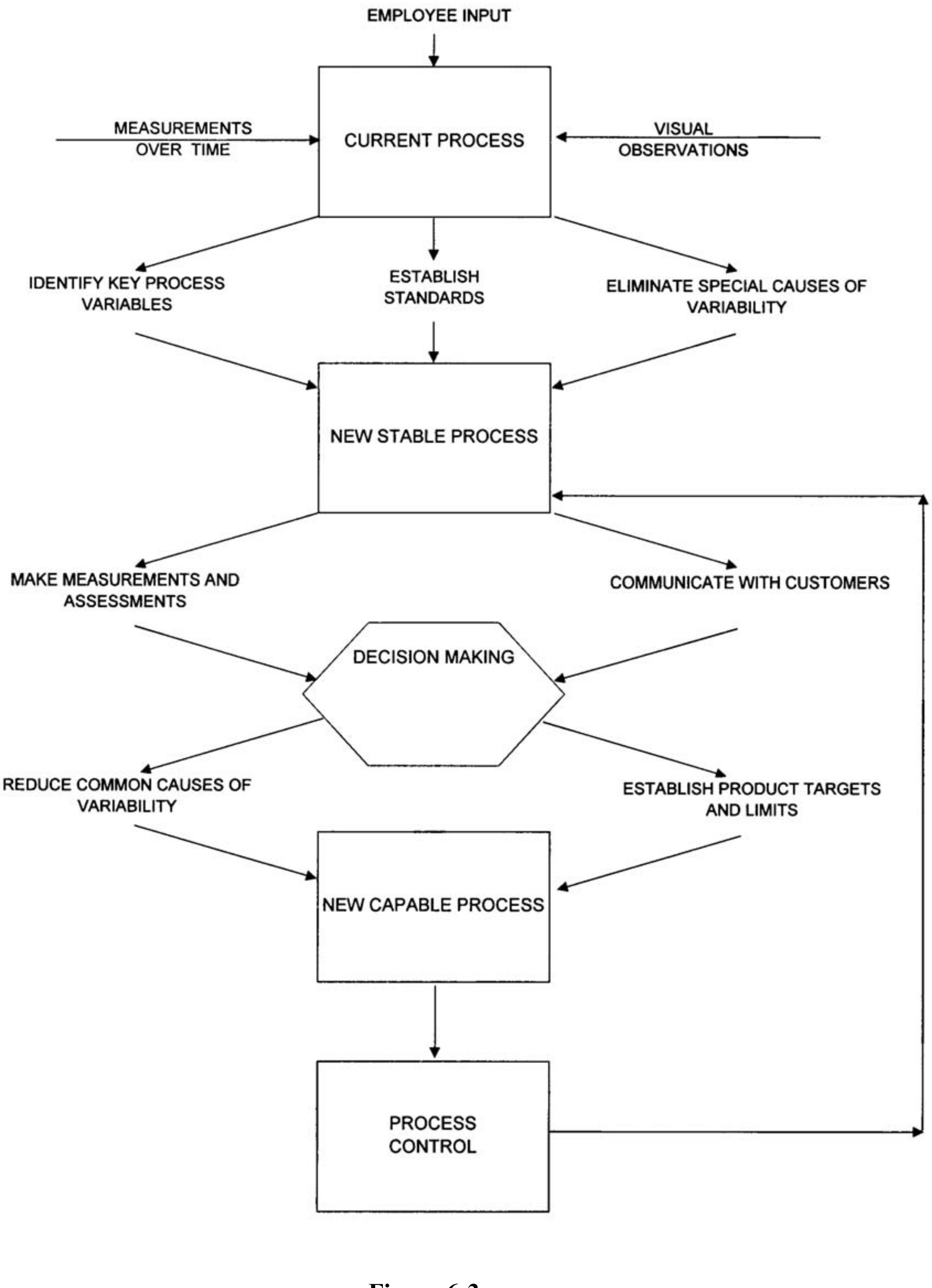


Figure 6-3.

STATISTICAL CONCEPTS

The only way to exercise complete control and make improvements on any process is to take accurate measurements at critical points within the process. In order to gain confidence, the numbers must be generated often at various points so that all the variations of the process are detected. The quantity of measurements over time will accumulate and simple tables or listings of these numbers will not be enough to evaluate the process. The following statistical tools will help the technician to understand what the numbers mean.

DATA SETS

The numbers from measurements that represent something in common rather than a scattering of unrelated numbers are called a **set**. When measuring properties of the process that are different; for example, gradation, crush count, or chert count, each property will require its own set of numbers. Also, each property has different sets of numbers for different points in the process if the characteristics are known to change. (For example, production gradations versus stockpile gradations). Furthermore, even when properties and points of sampling are the same, a new set of data will have to be created if there is a significant sustained change in the process. All the efforts at understanding, controlling, and predicting the outcome of a process are only as good as the accuracy and make-up of the related data sets. The importance of this step should not be underestimated.

THE MEAN

The average of all the data over time of an unchanged process is sometimes called the "grand mean" or the "population mean." For a shorter snapshot in time it may be called the "local mean" or just the "**mean**." The mean is the center of any distribution of numbers. Figure 6-4 is a graph of a very large group of numbers that are equally distributed on each side of the mean ($\bar{x}$). The graphic representation of these numbers is called a "standard bell curve".

STANDARD DEVIATION

Whereas the mean is an average of all the data values, the **standard deviation** is an average value, so to speak, of the dispersion of data from the mean. It shows how much the process varies. The standard deviation determines the shape of the bell curve. Small values reflect a tall, narrow curve (good), while large values reflect a flat, broad curve (poor).

NORMAL DISTRIBUTION

To simplify the interpretation of the data sets, the assumption is made that the data mathematically falls into a **normal distribution** which when plotted resembles the bell shaped curve. Although few actual processes will exactly follow this assumption, they will be close enough when stable and in control to be useful statistically. By assuming a normal distribution of the data, a few simple formulas can be applied to give the desired picture of the process. Any area under the bell curve falling between certain limits from left to right when expressed as a percentage of the total will indicate the portion of that process that conforms to those limits (Figure 6-4). The further data values move right or left from the center of the curve, the less often those values will occur.

Some values that serve as handy reference points for the normal distribution are:

1) About two-thirds of the area under the normal curve lies between one standard deviation below the mean and one standard deviation above the mean;

2) About 95 percent lies between plus and minus two standard deviations; and

3) About 99.75 percent lies within three standard deviations of the mean.

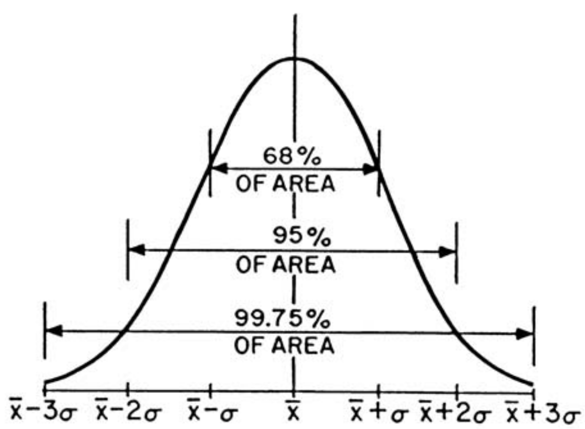


Figure 6-4. Normal Distribution

VARIABILITY

As previously mentioned, special causes are a source of variability that render the process unstable and unpredictable. If the mean and standard deviation change over time, nothing can be assumed and no control is possible. When the mean and standard deviation of the data set for each smaller increment of time is very close to each succeeding one over time, then the process is in control and special causes of variation have been eliminated (Figure 6-5).

In-control conditions should be achieved for each critical characteristic and point in the process. Keep in mind that sources of variability for the same characteristic at different points in the process are cumulative. During the production, handling, and stockpiling of mineral aggregates, the sources of error are potentially many. Therefore, controls must be instituted upstream as well as throughout the process. Also, sampling and testing error may affect the variability. Although sampling and testing error will not affect the actual variation of the process, the misleading information can cause incorrect control techniques to be employed and possibly increase variability in the product. The lower the sampling and testing error, the more indicative the data will be of the process.

CAPABILITY AND COMPLIANCE

The mean, standard deviation and variance tell the location of the process and how consistent it is. This is very important in exercising control. By themselves, however, they do not indicate how well the process will meet certain specifications or other limits agreed to with a customer. The ability of the process to comply with externally imposed limits is called **capability**. The first useful tool in making this assessment is the **Z** value. Very simply, this value indicates the number of standard deviations that the mean is from a particular limit. Many specifications address the **Z** value and the standard deviation as a requirement. The greater the **Z** value, the more compliant or capable the process is (Figure 6-6). If the data is reflective of the total material, then the actual percent of material falling within the prescribed limits can be determined from the **Z** value and the following table. Table 6-2 gives a cumulative solution when upper and lower boundaries exclude portions of both tails of the process distribution. For the CAP Program the **Z** value must <u>always be 1.65 or greater</u> when applied to the critical sieve for coarse aggregate products.

The **Z** value is used for:

1. Process Compliance -- Production data runs; and
2. Product Compliance -- Shipping data

Producers may also use these statistical techniques to determine gradation compliance on other sieves or for other properties where control is desired.

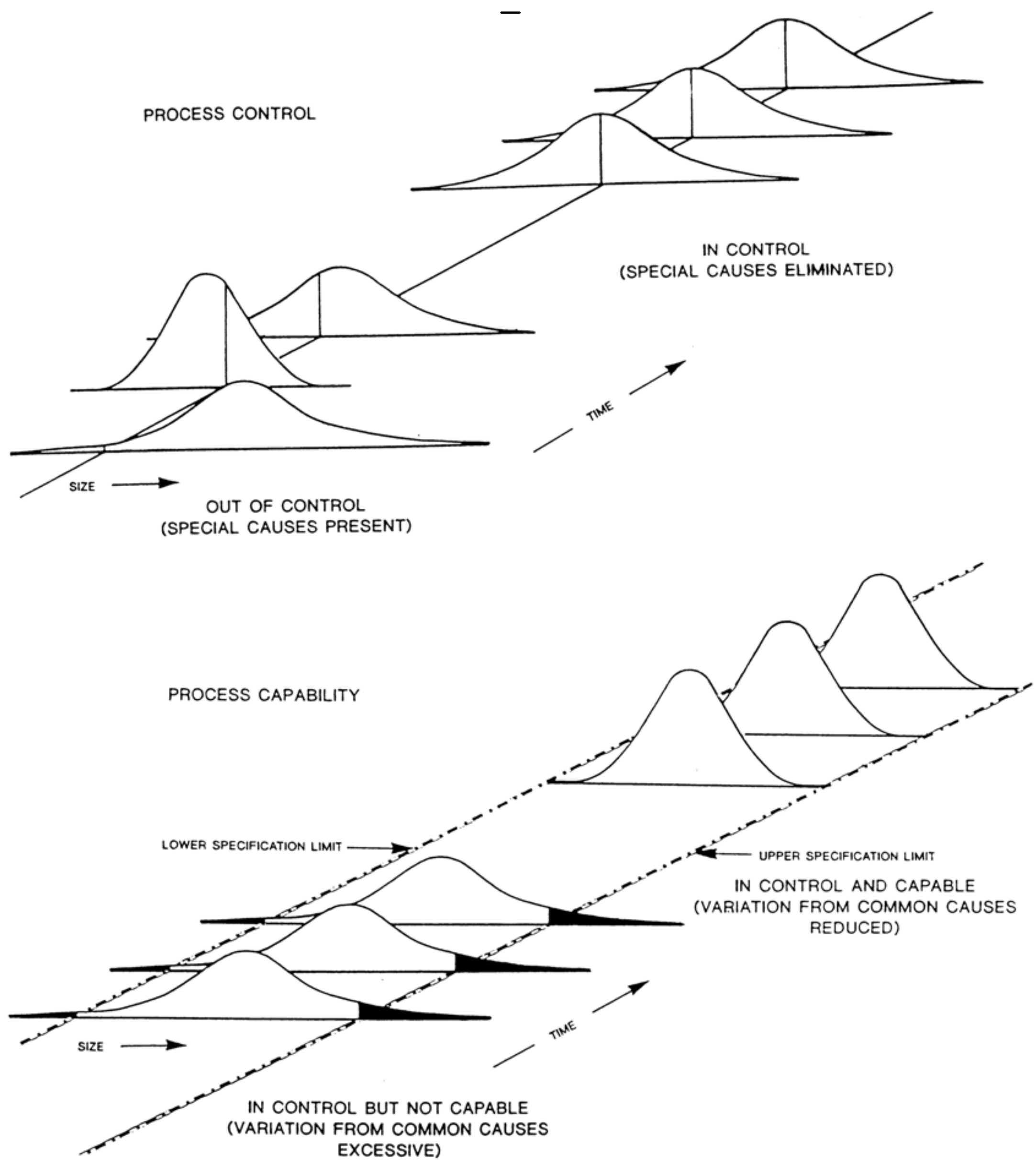


Figure 6-5. Process control and capability.

The Z Value

$$Z_{Upper} = \frac{UpperLimit - \overline{X}}{\sigma_{n-1}}$$

$$Z = \frac{X_{Limit} - \overline{X}}{\sigma_{n-1}}$$

$$Z_{Lower} = \frac{\overline{X} - LowerLimit}{\sigma_{n-1}}$$

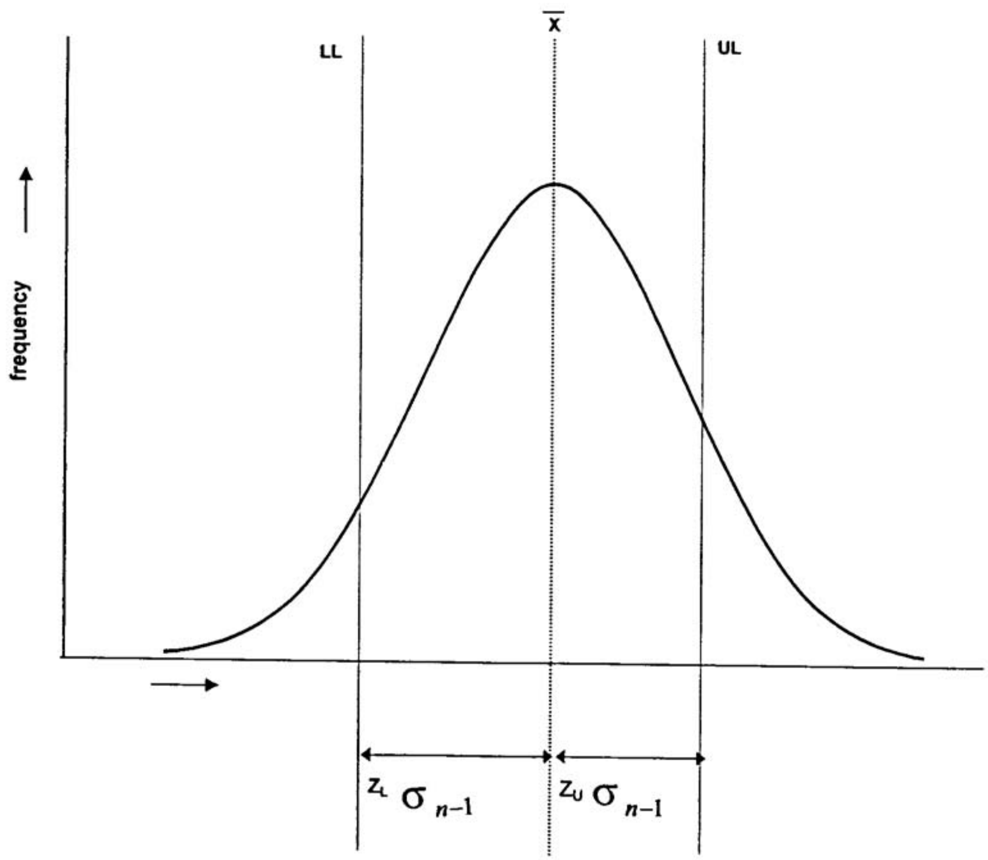
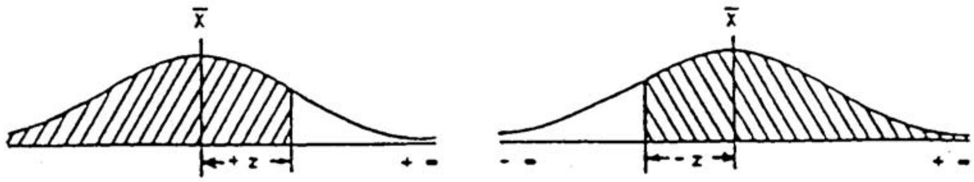


Figure 6-6. The area under the curve between the mean ($\overline{x}$) and another point (x), depends on Z which is the arithmetic difference between x and x, divided by the standard deviation (σ_{n-1}).

When the **Z** value to the nearest limit is known, this table indicates the area of probability between limits when one limit is 0 or 100 and the other is a number less than 100. The resultant area factor should be multiplied by 100 to give the percent probability of compliance.



z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.5000	.5040	.5080	.5120	.5160	.5199	.5239	.5279	.5319	.5359
0.1	.5398	.5438	.5478	.5517	.5557	.5596	.5636	.5675	.5714	.5753
0.2	.5793	.5832	.5871	.5910	.5948	.5987	.6026	.6064	.6103	.6141
0.3	.6179	.6217	.6255	.6293	.6331	.6368	.6406	.6443	.6480	.6517
0.4	.6554	.6591	.6628	.6664	.6700	.6736	.6772	.6808	.6844	.6879
0.5	.6915	.6950	.6985	.7019	.7054	.7088	.7123	.7157	.7190	.7224
0.6	.7257	.7291	.7324	.7357	.7389	.7422	.7454	.7486	.7517	.7549
0.7	.7580	.7611	.7642	.7673	.7704	.7734	.7764	.7794	.7823	.7852
0.8	.7881	.7910	.7939	.7967	.7995	.8023	.8051	.8078	.8106	.8133
0.9	.8159	.8186	.8212	.8238	.8264	.8289	.8315	.8340	.8365	.8389
1.0	.8413	.8438	.8461	.8485	.8508	.8531	.8554	.8577	.8599	.8621
1.1	.8643	.8665	.8686	.8708	.8729	.8749	.8770	.8790	.8810	.8830
1.2	.8849	.8869	.8888	.8907	.8925	.8944	.8962	.8980	.8997	.9015
1.3	.9032	.9049	.9066	.9082	.9099	.9115	.9131	.9147	.9162	.9177
1.4	.9192	.9207	.9222	.9236	.9251	.9265	.9279	.9292	.9306	.9319
1.5	.9332	.9345	.9357	.9370	.9382	.9394	.9406	.9418	.9429	.9441
1.6	.9452	.9463	.9474	.9484	.9495	.9505	.9515	.9525	.9535	.9545
1.7	.9554	.9564	.9573	.9582	.9591	.9599	.9608	.9616	.9625	.9633
1.8	.9641	.9649	.9656	.9664	.9671	.9678	.9686	.9693	.9699	.9706
1.9	.9713	.9719	.9726	.9732	.9738	.9744	.9750	.9756	.9761	.9767
2.0	.9772	.9778	.9783	.9788	.9793	.9798	.9803	.9808	.9812	.9817
2.1	.9821	.9826	.9830	.9834	.9838	.9842	.9846	.9850	.9854	.9857
2.2	.9861	.9864	.9868	.9871	.9875	.9878	.9881	.9884	.9887	.9890
2.3	.9893	.9896	.9898	.9901	.9904	.9906	.9909	.9911	.9913	.9916
2.4	.9918	.9920	.9922	.9925	.9927	.9929	.9931	.9932	.9934	.9936
2.5	.9938	.9940	.9941	.9943	.9945	.9946	.9948	.9949	.9951	.9952
2.6	.9953	.9955	.9956	.9957	.9959	.9960	.9961	.9962	.9963	.9964
2.7	.9965	.9966	.9967	.9968	.9969	.9970	.9971	.9972	.9973	.9974
2.8	.9974	.9975	.9976	.9977	.9977	.9978	.9979	.9979	.9980	.9981
2.9	.9981	.9982	.9982	.9983	.9984	.9984	.9985	.9985	.9986	.9986
3.0	.9987	.9987	.9987	.9988	.9988	.9989	.9989	.9989	.9990	.9990
3.1	.9990	.9991	.9991	.9991	.9992	.9992	.9992	.9992	.9993	.9993
3.2	.9993	.9993	.9994	.9994	.9994	.9994	.9994	.9995	.9995	.9995
3.3	.9995	.9995	.9995	.9996	.9996	.9996	.9996	.9996	.9996	.9997
3.4	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9997	.9998

TABLE 6-1. AREA OF PROBABILITY TABLE
<u>FOR SPECIFICATIONS INVOLVING 0 PERCENT AND 100 PERCENT</u>

When the **Z** values to each limit are known, this table indicates the area of probability between limits by summing the area left of the $\bar{x}$ with the area right of the $\bar{x}$. The sum of the two area factors should be multiplied by 100 to give the percent probability of compliance.

z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	.0000	.0040	.0080	.0120	.0159	.0199	.0239	.0279	.0319	.0359
0.1	.0398	.0438	.0478	.0517	.0557	.0596	.0636	.0675	.0714	.0753
0.2	.0793	.0832	.0871	.0910	.0948	.0987	.1026	.1064	.1103	.1141
0.3	.1179	.1217	.1255	.1293	.1331	.1368	.1406	.1443	.1480	.1517
0.4	.1554	.1591	.1628	.1664	.1700	.1736	.1772	.1808	.1844	.1879
0.5	.1915	.1950	.1985	.2019	.2054	.2088	.2123	.2157	.2190	.2224
0.6	.2257	.2291	.2324	.2357	.2389	.2422	.2454	.2486	.2518	.2549
0.7	.2580	.2612	.2642	.2673	.2704	.2734	.2764	.2794	.2823	.2852
0.8	.2881	.2910	.2939	.2967	.2995	.3023	.3051	.3078	.3106	.3233
0.9	.3159	.3186	.3212	.3238	.3264	.3289	.3315	.3340	.3365	.3389
1.0	.3413	.3438	.3461	.3485	.3508	.3531	.3554	.3577	.3599	.3621
1.1	.3643	.3665	.3686	.3708	.3729	.3749	.3770	.3790	.3810	.3830
1.2	.3849	.3869	.3888	.3907	.3925	.3944	.3962	.3980	.3997	.4015
1.3	.4032	.4049	.4066	.4083	.4099	.4115	.4131	.4147	.4162	.4177
1.4	.4192	.4207	.4222	.4236	.4251	.4265	.4279	.4292	.4306	.4319
1.5	.4332	.4345	.4357	.4370	.4382	.4394	.4406	.4418	.4430	.4441
1.6	.4452	.4463	.4474	.4485	.4495	.4505	.4515	.4525	.4535	.4545
1.7	.4554	.4564	.4573	.4582	.4591	.4599	.4608	.4616	.4625	.4633
1.8	.4641	.4649	.4656	.4664	.4671	.4678	.4686	.4693	.4699	.4706
1.9	.4713	.4719	.4726	.4732	.4738	.4744	.4750	.4758	.4762	.4767
2.0	.4773	.4778	.4783	.4788	.4793	.4798	.4803	.4808	.4812	.4817
2.1	.4821	.4826	.4830	.4834	.4838	.4842	.4846	.4850	.4854	.4857
2.2	.4861	.4865	.4868	.4871	.4875	.4878	.4881	.4884	.4887	.4890
2.3	.4893	.4896	.4898	.4901	.4904	.4906	.4909	.4911	.4913	.4916
2.4	.4918	.4920	.4922	.4925	.4927	.4929	.4931	.4932	.4934	.4936
2.5	.4938	.4940	.4941	.4943	.4945	.4946	.4948	.4949	.4951	.4952
2.6	.4953	.4955	.4956	.4957	.4959	.4960	.4961	.4962	.4963	.4964
2.7	.4965	.4966	.4967	.4968	.4969	.4970	.4971	.4972	.4973	.4974
2.8	.4974	.4975	.4976	.4977	.4977	.4978	.4979	.4980	.4980	.4981
2.9	.4981	.4982	.4983	.4984	.4984	.4984	.4985	.4985	.4986	.4986
3.0	.49865	.4987	.4987	.4988	.4988	.4988	.4989	.4989	.4989	.4990
3.1	.49903	.4991	.4991	.4991	.4992	.4992	.4992	.4992	.4993	.4993
3.2	.49931									
3.3	.49952									
3.4	.49966									

Table 6-2. AREA OF PROBABILITY TABLE
FOR SPECIFICATIONS INVOLVING > 0 PERCENT AND < 100 PERCENT

The CAP Program (**ITM 211**) states that 95 percent of all gradation test results on the critical sieve shall statistically be between 10 percent below and 10 percent above the target mean at any one point of sampling. An example of how to calculate percent compliance is as follows:

Product: #8 Stone
Critical Sieve: 1/2 in.
QCP Target Mean: 52.2%

The most recent 30 production sample test results:

55.5	49.4	49.5	55.6	61.3
51.2	46.0	50.8	53.8	49.7
53.2	42.4	50.5	52.8	54.6
56.4	53.1	55.2	53.6	58.1
54.2	65.7	56.1	52.6	56.4
48.1	50.3	59.1	52.1	50.9

$\bar{x} = \underline{53.3}$ $\sigma_{n-1} = \underline{4.53}$

$$Z_{upper} = \frac{(\text{QCP Target Mean} + 10) - \bar{x}}{\sigma_{n-1}} = \frac{(52.2 + 10) - 53.3}{4.53} = 1.96$$

from Table 6-2, 1.96 is .4750

$.4750 \times 100 = \underline{47.50}$

$$Z_{lower} = \frac{\bar{x} - (\text{QCP Target Mean} - 10)}{\sigma_{n-1}} = \frac{53.3 - (52.2 - 10)}{4.53} = 2.45$$

from Table 6-2, 2.45 is .4929

$.4929 \times 100 = \underline{49.29}$

% Compliance = $47.50 + 49.29 = 96.79 \approx 97$
(Whole No.)

CONTROL CHARTING

We know that controlling a process with one measurement is impossible. Also, only a few measurements will not provide the level of confidence needed for proper decision-making and a clear picture of the process. The only way control and decisions can be made with confidence is through use of large data sets. How can the operator be guided on a daily basis when faced with such overwhelming information? The answer is the **control chart**. Graphic representation of the data shown in conjunction with prescribed limits can provide the operator with everything that is needed if used with the proper interpretation techniques.

WHEN TO USE CHARTS

INDOT requires that gradation control charts be maintained for most products made by a certified plant for ultimate use on state contracts. Refer to the CAP Program for further instructions. Also, any characteristic that is critical to a product becomes a candidate for control charting; for example, crush count, chert count, or any other characteristics that may apply. In these cases, the items considered and the proposed limits should be included in the Quality Control Plan submitted to INDOT for approval.

CONTROL CHART LEGEND

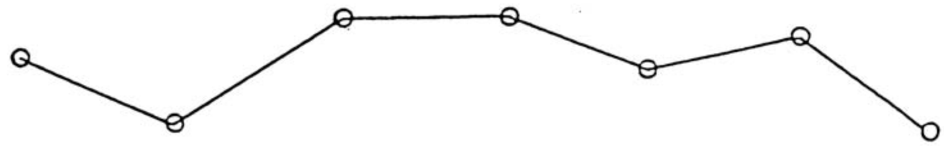
CAPP establishes a legend for specific information to be plotted on control charts. This legend convention shall be followed, except that any proposed deviation from the procedures shall be clearly identified in the Quality Control Plan.

The target mean is represented by a heavy long dash followed by a short dash.

Control limits are represented by heavy solid lines placed at plus and minus two standard deviations, but no greater than plus or minus 10 percent from the target mean.

Upper and lower specification limits are indicated by short dashed lines.

Production plot points are be surrounded by small circle and each consecutive point is connected by a solid straight line.



The moving average plot point is indicated by a small triangle and connected by straight lines.

The stockpile loadout plot points is indicated by a small square. ⊡

BEGINNING THE CONTROL CHART

The principle purpose of the control chart is to visually depict a repeatable and controlled process. If the new data is expected to be part of the process population, then some definition of the process is required. The entire chart is centered around the **target mean value**. Ideally, the target mean should be the grand mean which would be based on as much data as possible (perhaps a year), providing the process has not changed (Table 6-3 and Figure 6-7). If valid data does not exist on the process, then set up the control chart around a mean calculated from the first ten test results (Figure 6-8). After reiterating the "Steps for Managing Quality" several times to ensure a stable and capable process and building a more extensive data-base, the target mean value should then be checked for appropriateness. If a change is necessary, the customers should be consulted. The CAPP requires a QCP Annex to the Quality Control Plan identifying the new target mean to be filed with INDOT. Next, control limits should be added at plus and minus 2 standard deviations from the target mean. In no case shall these limits exceed plus and minus 10 percent. Check the **Z** value to make sure it is 1.65 or greater. If it is not, the process must be changed.

A quick check of the location of the target mean in relation to the closest specification limit is to multiply 1.65 times the standard deviation. Then, either add or subtract the value, as appropriate, to the target mean. If the resultant number falls outside the specification band, the current process does not meet the requirements of CAPP (Specification Limit Check in Table 6-3).

PLANT: INDIANA MATERIAL SIZE: INDOT #9

SPEC.	100	60 - 85	30 - 60	0 - 15	0 - 10
SIEVE	3/4 in.	1/2 in.	3/8 in.	No. 4	No. 8
Mar 19	100.0	68.9	38.4	4.9	2.3
Mar 19	100.0	71.2	40.8	5.2	2.9
Mar 25	100.0	70.8	36.4	3.3	2.8
Mar 25	100.0	69.8	35.2	4.5	3.6
Mar 27	100.0	69.2	37.7	3.9	2.2
Mar 31	100.0	66.3	36.9	3.3	2.1
Mar 31	100.0	70.1	40.1	3.9	2.5
Apr 6	100.0	68.0	37.2	3.6	2.8
Apr 6	100.0	69.7	34.1	3.5	2.8
Apr 8	100.0	71.6	35.1	3.0	1.9
Apr 8	100.0	70.9	37.5	3.7	2.6
Apr 11	100.0	74.8	46.0	4.0	3.1
Apr 15	100.0	77.4	42.9	3.9	1.8
Apr 17	100.0	80.3	49.2	4.9	3.1
Apr 17	100.0	74.0	34.5	3.9	2.4
Apr 20	100.0	73.4	35.4	2.9	1.9
Apr 20	100.0	79.3	40.1	4.4	3.0
Apr 21	100.0	77.5	39.7	4.0	3.2
Apr 21	100.0	78.4	43.1	3.7	2.1
Apr 22	100.0	75.2	39.7	3.6	2.3
Apr 24	100.0	80.9	45.1	4.5	1.9
Apr 24	100.0	80.4	46.5	4.6	2.3
Apr 25	100.0	75.5	38.5	3.5	1.9
Apr 30	100.0	77.2	38.0	5.8	3.6
Apr 30	100.0	76.8	42.2	3.3	2.2
MEAN	100.0	73.9	39.6	4.0	2.5
STD. DEV.	0.000	4.34	4.05	0.71	0.54

For the 3/8 in. Critical Sieve: $n = 25$, $\bar{x} = 39.6$, $\sigma_{n-1} = 4.05$

Specification Limit Check

1.65 times $\sigma_{n-1} = 1.65(4.05) = 6.7$

Upper Specification Limit (USL) check = 39.6 + 6.7 = **46.3 ≤ 60 OK!**

Lower Specification Limit (LSL) check = 39.6 - 6.7 = **32.9 ≥ 30 OK!**

Z Value Check

$$Z_u = \frac{60-39.6}{4.05} = 5.04 > 1.65$$

$$Z_L = \frac{39.6 - 30.0}{4.05} = 2.37 > 1.65$$

Establish Control Limits

Upper Control Limit (UCL) = $\bar{x} + 2\,\sigma_{n-1} = 39.6 + 2(4.05) =$ **47.7 or 48**

Lower Control Limit (LCL) = $\bar{x} - 2\,\sigma_{n-1} = 39.6 - 2(4.05) =$ **31.5 or 32**

Table 6-3. HISTORICAL DATA
GRADATION ANALYSIS

FROM HISTORICAL DATA

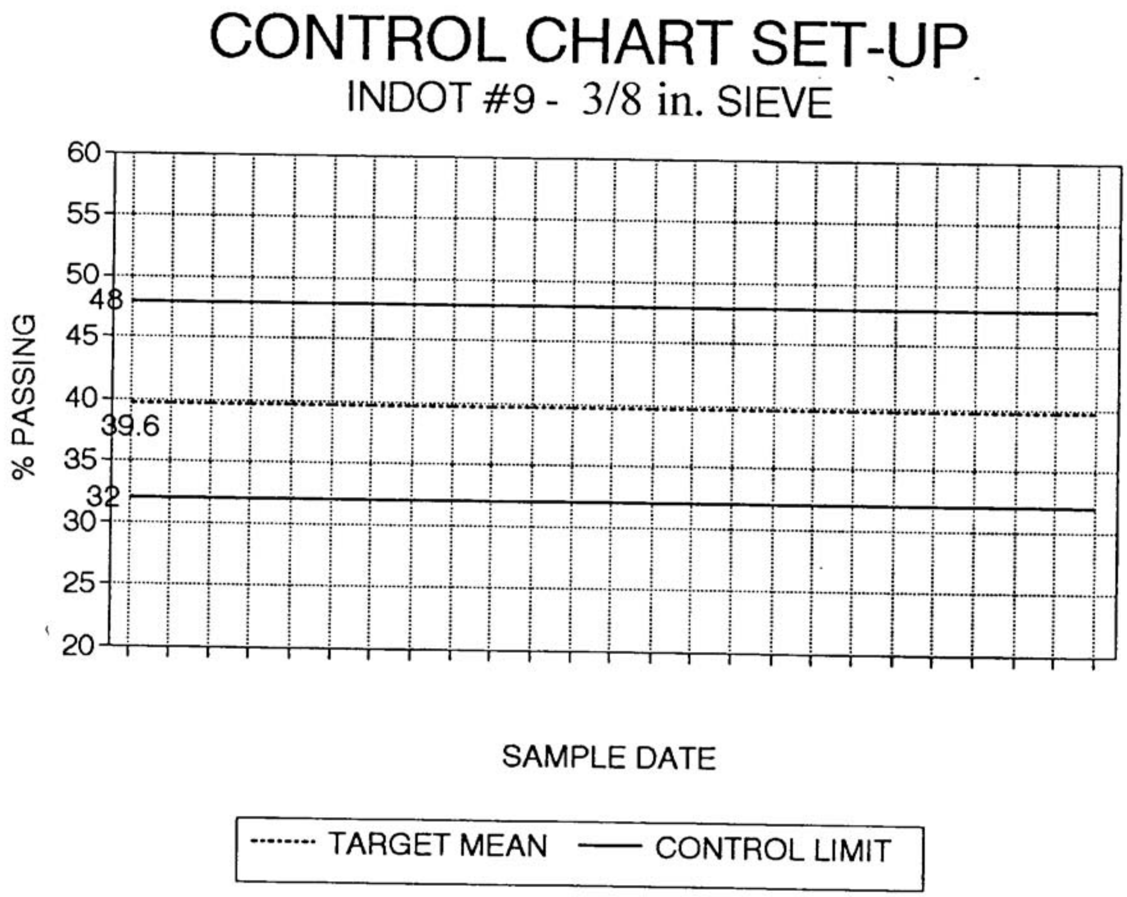


Figure 6-7.Control Chart Set-Up

FROM NEW DATA

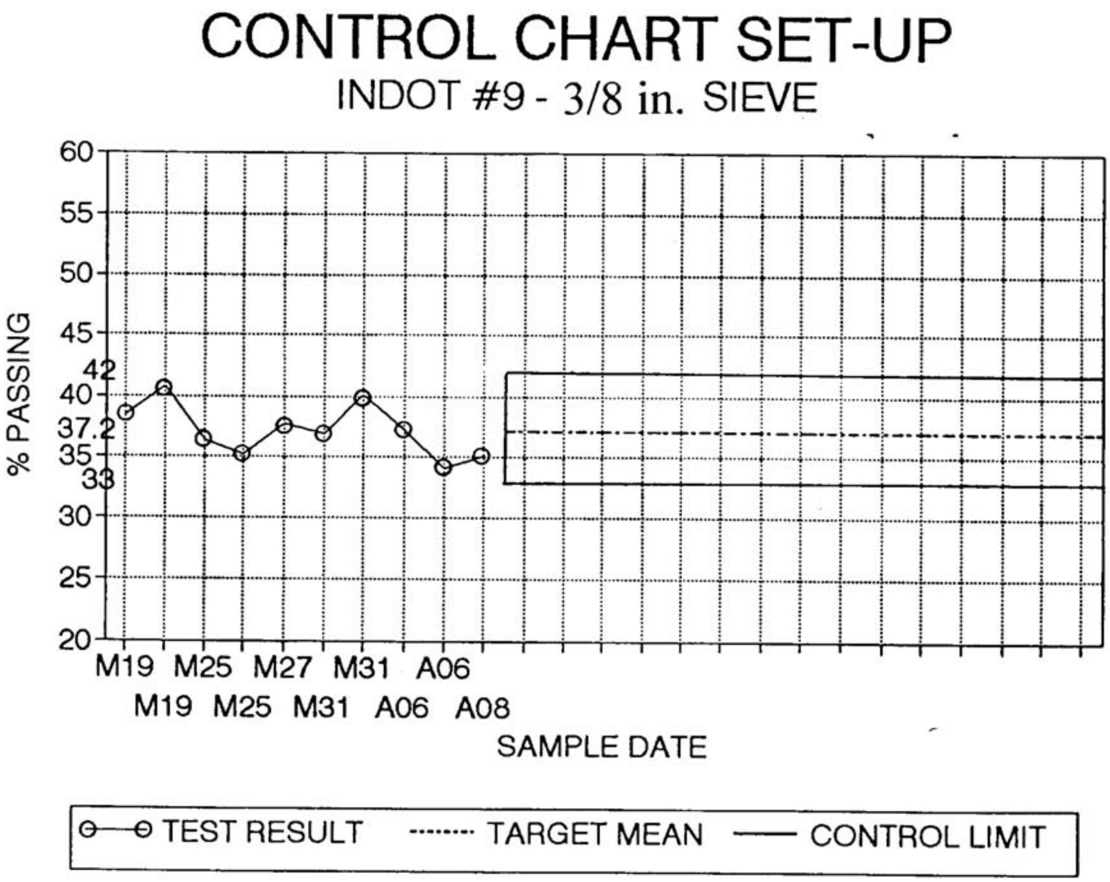


Figure 6-8. Control Chart Set-Up

PLOTTING THE DATA

If the process is in control and repeatable, then control charts must indicate to the manager and technician constant accuracy and precision. The scattering of individual data points will give a feel for precision or variability of the process when viewed against the control limits. In addition, a running average of the most current five data points are needed to track the accuracy of the process. Averages tend to lessen the effect of erratic data points that could reflect errors not related to the actual material (sampling, testing, etc.) and which distract the viewer away from trends comparing to the target mean. Although this technique is not as accurate as data points that are each comprised of averages of subsets and which require an accompanying chart of ranges, it works very well for the mineral aggregate industry. When aggregates are tested at frequencies of 2000 t per sample, it becomes unacceptable to wait for the accumulation of five tests before generating a single data point. Table 6-4 and Figure 6-9 illustrate how data points and the running average for a product critical sieve are plotted on a control chart with a pre-established target mean, and control limits.

The check of the specification limits and establishment of the control limits for Table 6-4 are performed as follows.

For the No. 4 critical sieve for the INDOT Standard Specifications #11 material:

<u>Data Set Results</u>

$n = 36$
$\bar{x} = 14.8$
$\sigma_{n-1} = 2.60$

<u>Specification Limit Check</u>

1.65 times $\sigma_{n-1} = 1.65(2.60) = 4.3$
USL check = 14.8 + 4.3 = **19.1** $\leq$ **30** OK
LSL check = 14.8 - 4.3 = **10.5** $\geq$ **10** OK

<u>Z Value Check</u>

$Z_u = \frac{30-14.8}{2.60} = 5.85 > 1.65$ OK

$Z_L = \frac{14.8 - 10}{2.60} = 1.85 > 1.65$ OK

<u>Establish Control Limits</u>

UCL = $\bar{x} + 2\ \sigma_{n-1} = 14.8 + 2(2.6) =$ **20.0** or **20**
LCL = $\bar{x} - 2\ \sigma_{n-1} = 14.8 - 2(2.6) =$ **9.6** or **10**

PLANT: INDIANA MATERIAL SIZE: #11

SPEC.	100	75 - 95	10 - 30	5 PT AVG	0 - 10
SIEVE	1/2 in.	3/8 in.	No. 4	No. 4	No. 8
Jun 3	100.0	87.5	13.1		3.3
Jun 4	100.0	86.7	17.9		4.4
Jun 4	100.0	90.8	17.9		6.1
Jun 5	100.0	85.9	15.1		5.7
Jun 8	100.0	87.1	10.8	**15.0**	3.9
Jun 8	100.0	89.6	15.4	**15.4**	5.1
Jun 9	100.0	84.8	10.4	**13.9**	3.9
Jun 9	100.0	84.8	16.2	**13.6**	3.8
Jun 10	100.0	85.2	14.4	**13.4**	4.9
Jun 10	100.0	88.9	17.8	**14.8**	3.1
Jun 11	100.0	86.2	12.2	**14.2**	4.4
Jun 12	100.0	87.2	14.1	**14.9**	5.3
Jun 12	100.0	86.0	13.0	**14.3**	4.9
Jun 12	100.0	87.7	16.2	**14.7**	4.5
Jun 15	100.0	82.0	16.1	**14.3**	4.2
Jun 16	100.0	88.3	14.4	**14.8**	5.4
Jun 16	100.0	89.7	11.8	**14.3**	3.5
Jun 16	100.0	89.4	12.5	**14.2**	4.7
Jun 17	100.0	86.2	11.5	**13.3**	2.9
Jun 18	100.0	86.1	14.7	**13.0**	4.3
Jun 19	100.0	88.5	11.2	**12.3**	5.4
Jun 19	100.0	86.0	18.7	**13.7**	3.3
Jun 19	100.0	87.4	14.8	**14.2**	5.8
Jun 19	100.0	87.5	12.1	**14.3**	3.3
Jun 22	100.0	85.9	16.0	**14.6**	4.9
Jun 22	100.0	96.3	14.0	**15.1**	4.5
Jun 23	100.0	86.9	11.3	**13.6**	3.7
Jun 24	100.0	88.5	16.3	**13.9**	4.2
Jun 25	100.0	88.6	15.0	**14.5**	5.0
Jun 25	100.0	89.5	16.9	**14.7**	5.5
Jun 26	100.0	86.6	13.9	**14.7**	5.0
Jun 29	100.0	87.9	14.7	**15.4**	5.1
Jun 29	100.0	89.6	16.7	**15.4**	6.2
Jun 30	100.0	90.1	18.2	**16.1**	8.8
Jun 30	100.0	92.3	21.8	**17.1**	8.3
Jun 30	100.0	90.7	14.0	**17.1**	4.1
MEAN	100.0	87.8	14.8		4.8
STD. DEV.	0.000	2.50	2.57		1.27

Table 6-4: GRADATION ANALYSIS

GOOD PROCESS CONTROL

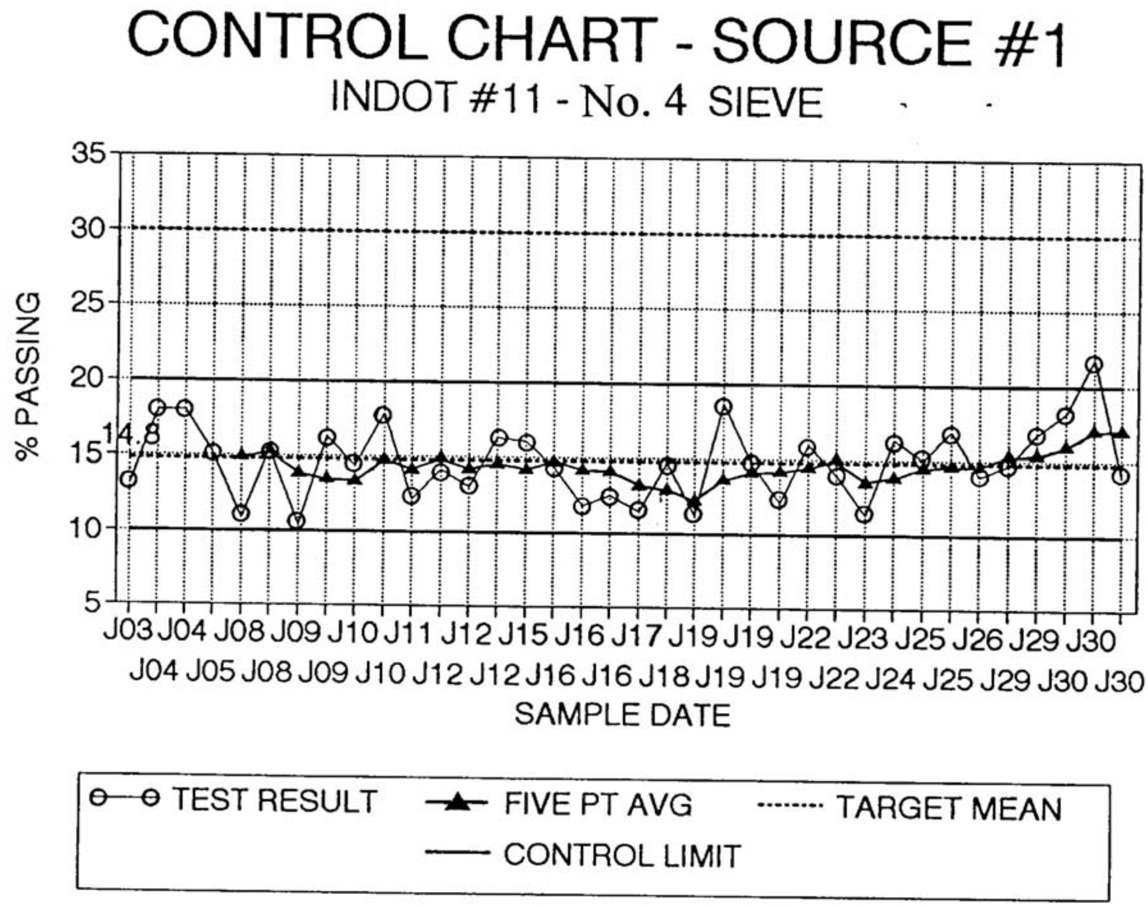


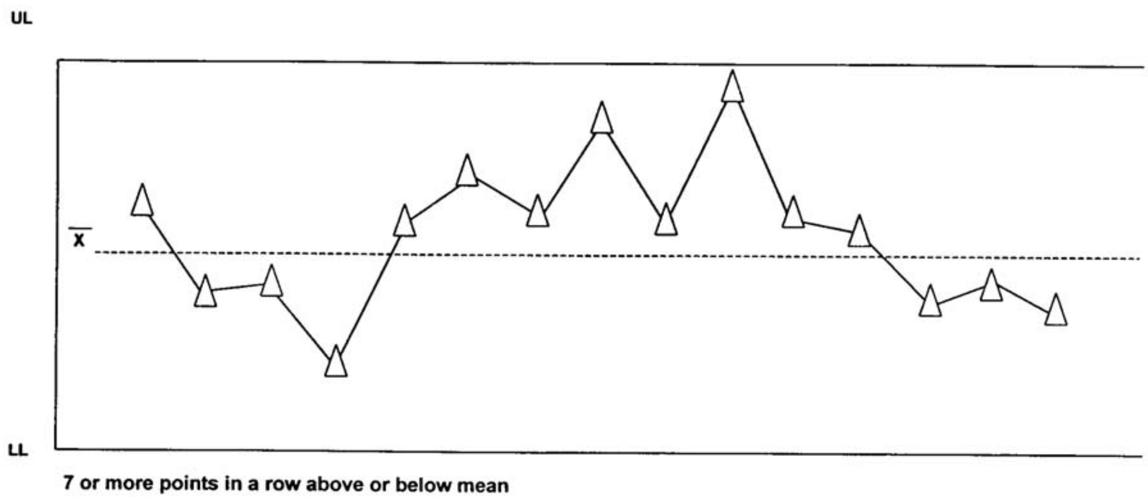
Figure 6-9. Good Process Control

Under the CAP Program specific treatment of nonconforming tests is required. Action must be taken after the first nonconforming test (outside of control limits). These requirements must be met in all cases and take precedence over any other control technique. When individual test results, even on an intermittent basis, frequently fall outside the control limits or specification limits, a nonconforming condition exists. A capability calculation in conjunction with whichever limits are being violated can quickly verify the condition. The following trends involving the 5-point moving average points (Figure 6-10) may require investigation by the Producer and as a minimum an entry in the diary to denote the problem.

1) Seven or more points in a row are above or below the target mean ($\bar{x}$); and/or

2) Seven or more points in a row are consistently increasing or decreasing

Finally, the technician should always be alert for a sudden jump in the data, whether it remains in control or not. This condition usually represents the addition of a completely different process and can be detected immediately without waiting for trends in the moving average (Figure 6-11). Corrective action should be taken immediately. If the shift to a new process is done with intent and is desired, then a clean break should be made in the control chart. After ten valid test results on the new process, a new target mean ($\bar{x}$) should be calculated and new control limits established (Figure 6-12).



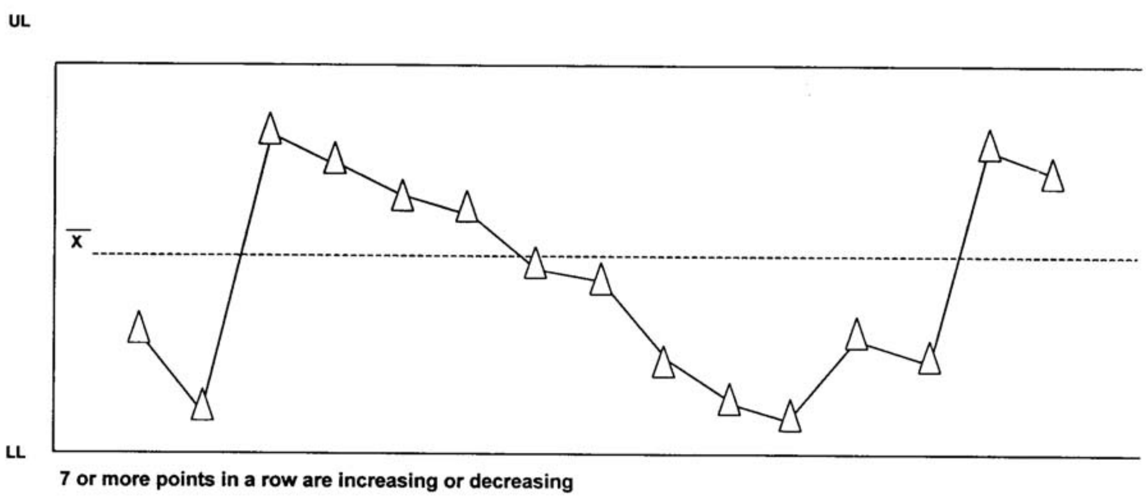


Figure 6-10. Five-Point Moving Average Trends

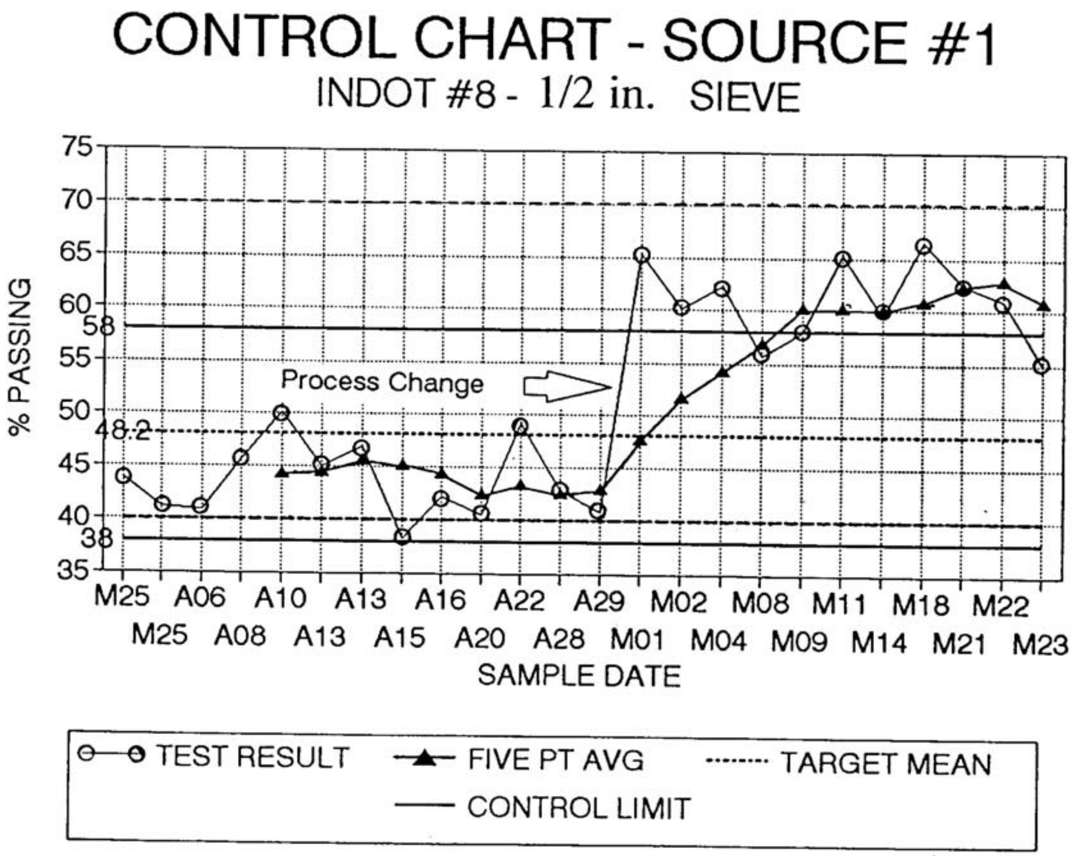


Figure 6-11. Nonconforming Process

PROCESS ADJUSTMENT

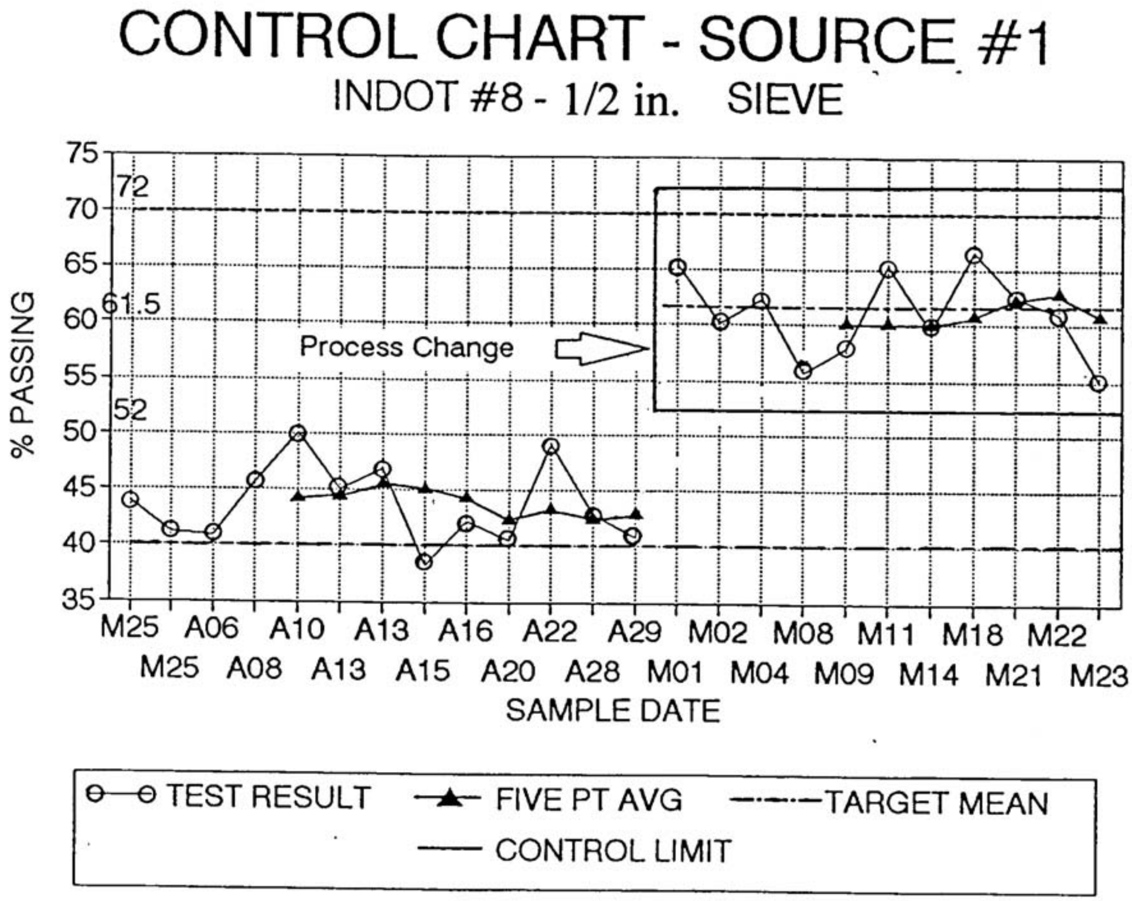


Figure 6-12. Process Adjustment